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Invited Review

Transport operations in container terminals: Literature overview, trends, research directions and classification scheme

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ABSTRACT

Internal transport operations connect the seaside, yard side, and landside processes at container terminals. This paper presents an in-depth overview of transport operations and the material handling equipment used, highlights current industry trends and developments, and proposes a new classification scheme for transport operations and scientific journal papers published up to 2012. The paper also discusses and challenges current operational paradigms of transport operations. Lastly, the paper identifies new avenues for academic research based on current trends and developments in the container terminal industry.

1. Introduction

Due to economic globalization, international trade continues to grow precipitately (UNCTAD, 2011). Globalization has not only increased the complexity of today's supply chain networks, but also has increased logistical challenges in the different nodes of supply chain networks. This paper describes the latest trends, developments, and literature on transport operations in container terminals, which have become essential nodes in today's supply chains.

Container trade is the fastest-growing freight segment with an annual average increase in volume of 8.2% between 1990 and 2010 (UNCTAD, 2011). In 2011 the world container port throughput was actually slower than previous years. However, with an increase of 5.9% the highest level ever was reached. The throughput slowdown in 2011 may be attributed to the economic crisis, conflict situations in North Africa and Western Asia, and natural disasters in Japan and Thailand (UNCTAD, 2012).

Containers are large metal boxes with standardized sizes. The two main container sizes are twenty-feet-equivalent-unit (TEU) and forty-feet-equivalent-unit (FEU). The dimensions of these containers are $20' \times 8' \times 8.5'$ ($6.1\ \text{m} \times 2.44\ \text{m} \times 2.59\ \text{m}$) and $40' \times 8' \times 8.5'$ ($12.2\ \text{m} \times 2.44\ \text{m} \times 2.59\ \text{m}$), respectively, although the height of the containers may vary. Thus, for all practical purposes, two TEUs are equivalent to one FEU. The dimensions of the containers allow them to be loaded into a platform to be transported by train or placed on a chassis and transported by truck.

Containerships are the preferred mode of transportation for containers over sea due to their economies of scale. The capacity of containerships has since 1955 continuously increased from several hundred containers to thousands of containers; the largest containerships today are capable of simultaneously transporting over 14,500 TEUs. Containerships typically operate under fixed maritime routes that include various container terminals in different countries. At every container terminal visited, import containers (i.e., those destined for that port) are unloaded and export containers (i.e., those departing from that port) are loaded. Table 1 presents the 20 busiest container ports in the world in terms of TEUs handled (Worldshipping, 2012). We note that the total volume handled in 2009 decreased by 10.5% compared to 2008 and the total volume handled in 2010 increased by 14.5% compared to 2009. Container terminals are continuously challenged to adjust their throughput capacity to match demand. Consequently, many opportunities arise for new approaches in container terminal design, material handling equipment, and operations research applications.

Container terminals can be divided into five main areas, namely the *berth*, *quay*, *transport area*, (*storage*) *yard*, and (*terminal*) *gate*. The berth and the quay areas are considered *seaside*, while the yard and gate areas are considered *landside*. The transport area (see Fig. 1), which is the main focus of this paper, is at the intersection of the seaside and landside areas. Common opinion is that transport operations should be designed so that bottlenecking in container terminals is avoided. This streamlining is important since seaside and landside operations directly depend on vehicles to pick up and load containers.

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Table 1
Busiest container ports in the world (in million TEUs) ranked as of 2011.

Rank	Port, country	2008	2009	2010	2011
1	Shanghai, China	27.98	25.00	29.07	31.74
2	Singapore, Singapore	29.92	25.86	28.43	29.94
3	Hong Kong, China	24.25	21.04	23.70	24.38
4	Shenzhen, China	21.41	18.25	22.51	22.57
5	Busan, South Korea	13.43	11.98	14.19	16.17
6	Ningbo-Zhoushan, China	11.23	10.50	13.14	14.72
7	Guangzhou Harbor, China	11.00	11.20	12.55	14.26
8	Qingdao, China	10.32	10.26	12.01	13.02
9	Dubai, United Arab Emirates	11.83	11.10	11.60	13.01
10	Rotterdam, Netherlands	10.80	9.74	11.14	11.88
11	Tianjin, China	8.50	8.70	10.08	11.59
12	Kaohsiung, Taiwan, China	9.68	8.58	9.18	9.64
13	Port Kelang, Malaysia	7.97	7.31	8.87	9.60
14	Hamburg, Germany	9.70	7.01	7.91	9.04
15	Antwerp, Belgium	8.66	7.31	8.47	8.66
16	Los Angeles, USA	7.85	6.75	6.50	7.94
17	Keihin Ports, Japan	n/a	n/a	7.48	7.64
18	Tanjung Pelepas, Malaysia	5.60	6.00	6.54	7.50
19	Xiamen, China	5.00	4.68	5.82	6.47
20	Dalian, China	n/a	n/a	5.24	6.4

The goal of this paper is to present a classification scheme for transport operations at container terminals based on examining the literature. The paper also aims to identify new avenues for academic research based on current trends and developments in the area of transport operations. Literature published in 2012 or before is classified according to the proposed scheme. However, only papers published after 2004 are discussed in detail as a partial follow up to Vis and De Koster (2003) which discussed papers published before 2004. In addition to Vis and De Koster (2003), two other overview papers on the operations of container terminals have been published so far: Steenken, Voß, and Stahlbock (2004), and Stahlbock and Voß (2008a). Stahlbock and Voß (2008b) present an overview of routing problems in container terminals related to the transportation as well to yard processes.

The remainder of the paper is organized as follows: Section 2 provides a description of transport operations and material handling equipment and elaborates on the industry trends and developments in transport operations. Section 3 presents an overview of the research output on transport operations up to 2012. Section 4 presents our classification scheme for transport operations literature. In Sections 5–9 we provide an in-depth overview of the literature on transport operations between 2004 and 2012, divided by the problems addressed. In Section 10 we step back to reconsider transport operations from an industrial engineering and operational excellence perspective in order to challenge current operational paradigms on transport operations. Lastly, Section 11 presents research avenues based on current trends and developments in the container terminal industry.

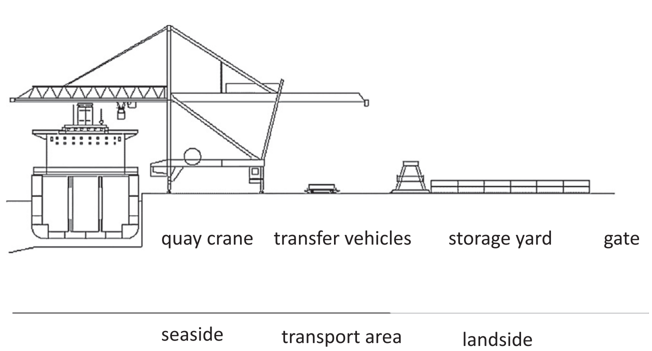

Fig. 1. Container terminal main areas.

2. Transport operations: A description and analysis of developments

In this section, we first describe the transportation process and relevant decision problems in relation to overall terminal processes (shown in Fig. 2) and specific types of transport vehicles. Second, we show industry trends and developments.

2.1. Decision problems in transport operations

The unloading process starts by assigning vessels to berths. Once a vessel has moored, one or more quay cranes (i.e., large, typically rail-mounted, semi-automated, gantry cranes located in the shore) unload the vessel following an unloading plan. The unloading time of a container depends on its location in the vessel and typically shows a large variance. The quay cranes retrieve export containers from the vessel's hold or deck and deposit them on the quay area or directly onto (internal) transport vehicles which then move the containers from the quay area to the yard area. Once a container is loaded onto a vehicle, it is transported to the storage yard where it is temporarily stored until it either is transported inland (by an external truck or train) or loaded onto another vessel. Import containers leave the container terminal through the terminal gates after their paperwork is verified and they are inspected (if selected for inspection). Typically, vessel loading occurs after all import containers have been unloaded and follows a stowage plan.

We distinguish between the following three main decision problems in transport operations. (1) *selecting the type of vehicle to use*, (2) *determining the number of vehicles required*, and (3) *routing and dispatching of vehicles*. Given the difference between the types of transfer vehicles, selecting the appropriate one requires a tradeoff between investment and operational costs, and performance. Typically, the modeling assumptions made to solve these three problems depend on the type of vehicle used. Therefore, we provide a description of the most common types of vehicles. For a detailed overview of different kinds of transport vehicles we refer to Brinkmann (2011).

Transport vehicles can be classified as self-lifting or non-lifting (see Fig. 3). Self-lifting vehicles, such as straddle carriers and automated lifting vehicles (ALVs) are able to lift containers from the ground autonomously. Non-lifting vehicles, such as yard trucks and automated guided vehicles (AGVs) require external material handling equipment to load/unload a container. Straddle carriers, depicted in Fig. 3a, are self-lifting vehicles that are capable of stacking containers up to several levels high. Hence, some terminals use straddle carriers as transfer and yard vehicles. Since straddle carriers need clearance on both sides of containers in order handle them, they require a special type of storage yard layout, shown in Fig. 4a. Straddle carriers are sometimes used merely as transfer vehicles in order to preserve the traditional layout organized by blocks as shown in Fig. 4b.

Unlike straddle carriers, AGVs (see Fig. 3b) do not have a stacking capability. The main characteristic of AGVs is that they are completely automated and controlled by a central computer which decides on the dispatching and movement of each vehicle. Several terminals including European Combined Terminal (ECT) in Rotterdam, Thamesport in London, HHLA Container Terminal Altenwerder (CTA) in Hamburg, use AGVs (Yang, Choi, & Ha, 2004). The main difference between ALVs and AGVs is the inability of AGVs to self-lift containers. Ranau (2011) study the difference between ALVs and AGVs from the perspective of dimensioning and layout of the transportation area. Yard trucks (Fig. 3c) are the most commonly used transfer vehicles in large container terminals given their comparatively low investment cost and large capacity. Yard trucks simply haul containers placed over a chassis. As opposed

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